Tropical Cyclone simulations with GFDL's prototype Global Cloud-Resolving Model (HiRAM)

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and

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NOAA/Geophysical Fluid Dynamics Laboratory

Workshop on "High-Resolution Climate Modeling", Aug 10, 2009

Outline

- Components of the GFDL prototype global cloud-resolving model [*aka*, **Hi**gh-**R**esolution **A**tmosphere **M**odel (**HiRAM**)]

- Adiabatic tests of ultra-high resolution (100-m to 1-km) global non-hydrostatic model on a very small planet

- Simulated tropical cyclone climatology with the C180 (~50 km) and C360 (~25 km) HiRam

- Deterministic forecasts with the C360 (~25 km) and C720 (~13 km) HiRam

  Examples::

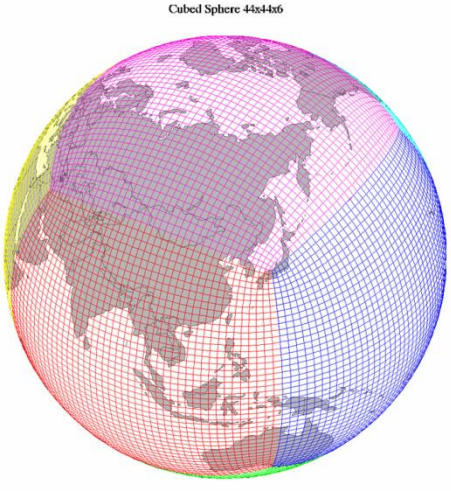
  – 5-day forecasts for HFIP (Hurricane Forecast Improvement Project)

  – 10-day forecast

Zhao, M., I. Held, S.-J. Lin, and G. Vecchi, 2009: Simulations of global hurricane climatology, interannual variability, and response to global warming using a 50km resolution GCM. *J. Climate. To appear.*

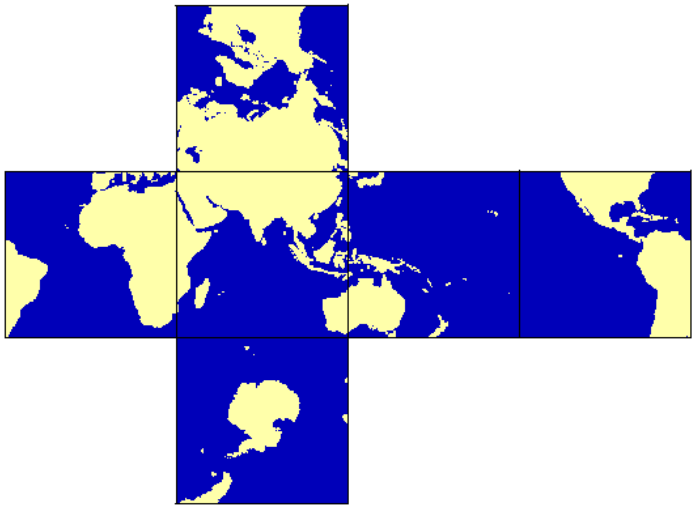
The GFDL High-Resolution Atmosphere Model (HiRAM) is developed for 1-100 km resolution, sharing most of the codes with the GFDL AM2/AM3, except the following major modifications

- N*on-hydrostatic Cubed-sphere Finite-Volume dynamical core.*
- *6-category single-moment bulk cloud microphysics with* computational efficiency significantly improved with time implicit treatment of microphysics processes and vertically Lagrangian terminal fall of all condensates (rain, snow, ice, and graupel)
- The deep convective parameterization scheme (Relaxed Arakawa-Schubert and the Donner scheme) is replaced by an essentially *non-precipitating shallow* convection scheme (based on *Bretherton et al.* 2004)
- *Surface fluxes modified for high-wind situation over ocean* (*Moon et al*. 2007)



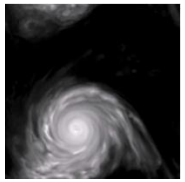
Gnomonic Cubed Sphere grid

- Defined by intersects of great circles with equal-distance along 12 edges
- Maximum local grid aspect ratio ~ 1.061
- Maximum global grid aspect ratio ~ 1.414



Resolutions:

1) IPCC AR5: C48 , Δx ~ 200 km
2) AMIP climate runs: C180 , Δx ~ 50 km
3) Medium-range forecast: C360 , Δx ~ 25 km
4) "cloud-resolving: C2000, Δx ~ 4.5 km



Can also be used as a regional model

Hurricane in a doubly periodic box

Generation of Lee vortices (vortex shedding)

(Hsu, National Taiwan University)

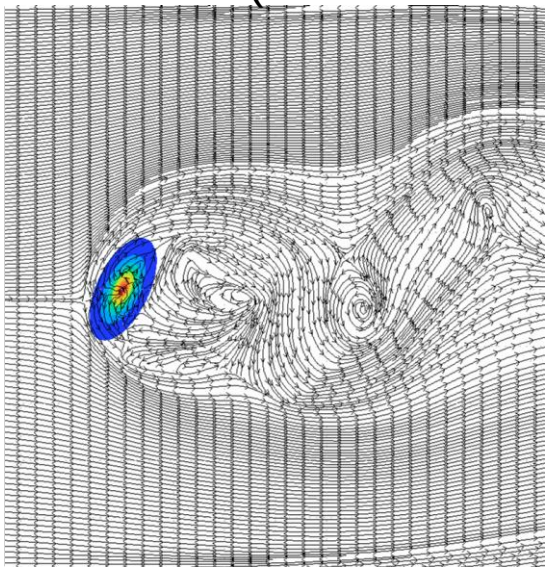
Bell-shaped mountain

$$h = \frac{h_{\max}}{\left[\frac{r\cos(\phi+\phi_0)}{a_x}\right]^2 + \left[\frac{r\sin(\phi+\phi_0)}{a_y}\right]^2 + 1}$$

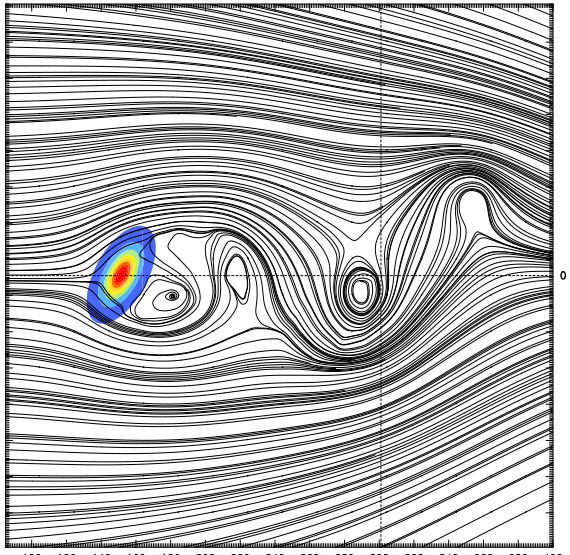
Mountain peak = 2 km
Model Domain: 600km x 600km
dx = dy = 1 km
dz ~ 300 m (top at ~ 15 km)
f=0
U = 4 m s^{-1}
$N^2 = 10^{-4}\ s^{-2}$
Half width lengths (a_x and a_y): 5 and 10 km (tilted by 30 degrees).
Fr = U/Nh = 0.2

1-km simulation: streamfunction (after 20-hr)

NTU-Purdue (Hsu and Sun 2001)

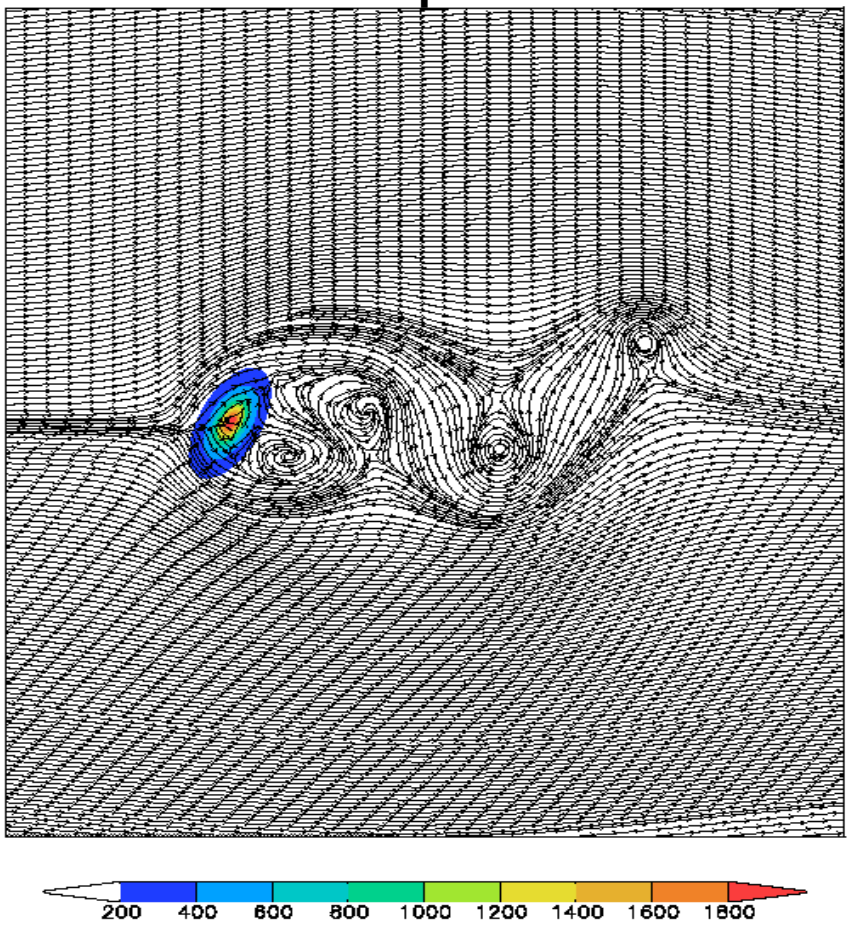


ARW WRF (Chen)



One face of the "small-radius" GFDL cubed-sphere model

~ 400 km



Adiabatic tests of the global non-hydrostatic model

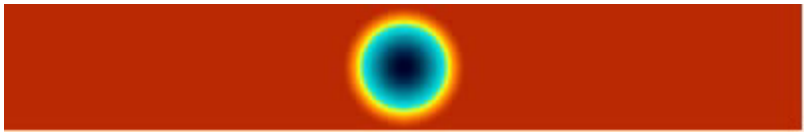
Density current (cold bubble) on a very small planet

Radius: 1000 X smaller than the Earth

resolution: ~100 m, model top at 6.4 km

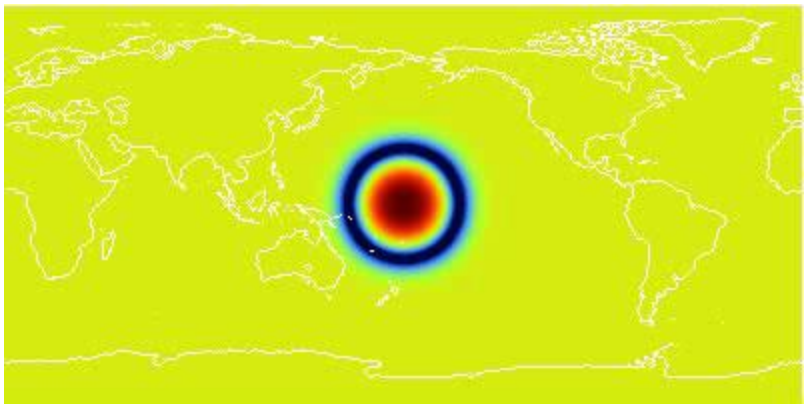
Simulation time = 10 min = 7 earth days

Vertical cross section: Θ →



6.4 km

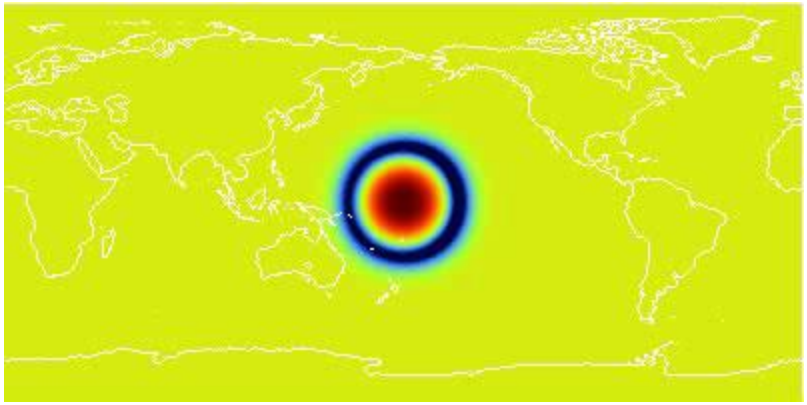
No rotation



PS

1000X faster rotation

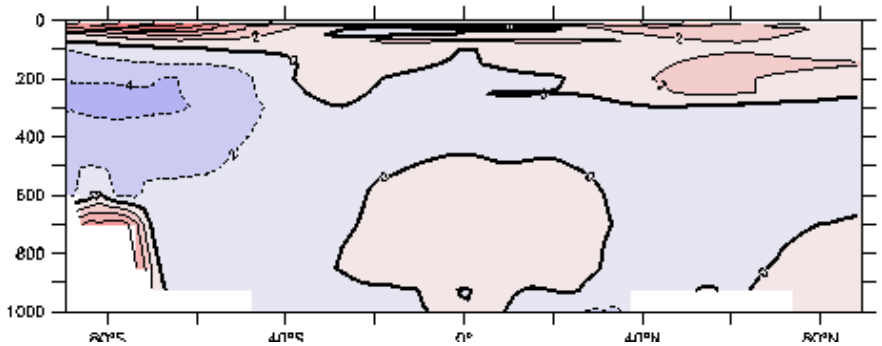
$$R = \frac{U}{\Omega L}$$



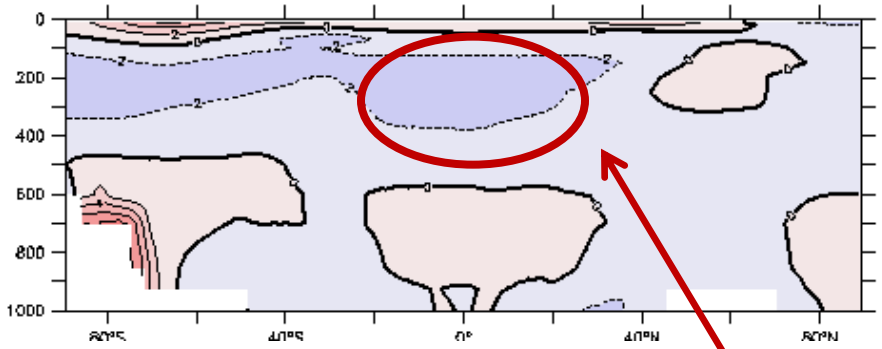
PS

Can the tropical cold bias be avoided without deep convective parameterization?

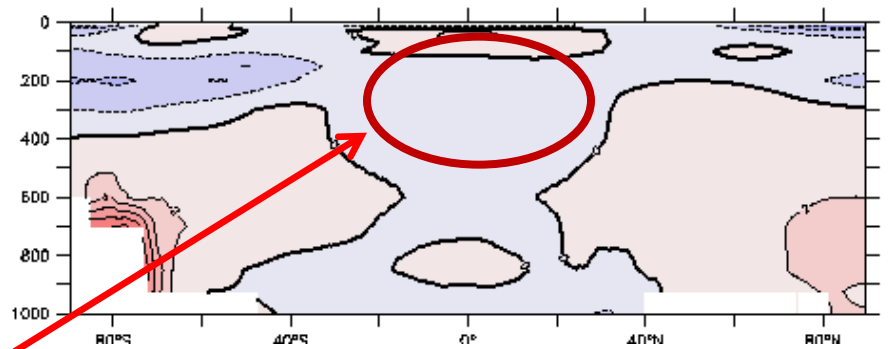
AM2.1 (2x2.5 deg.)



C90 cloud-resolving prototype



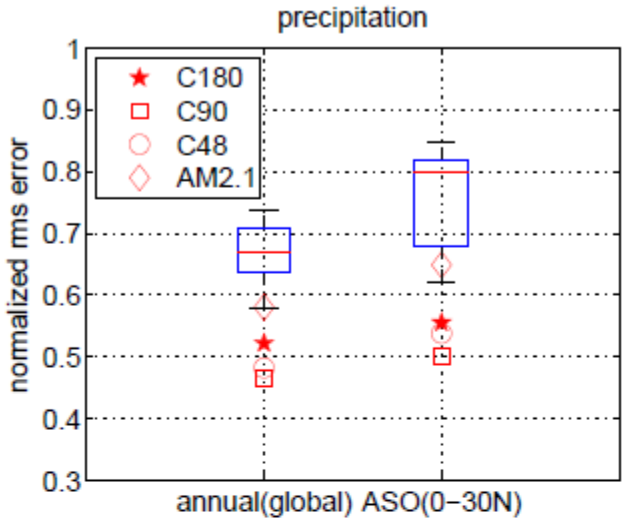
C360 cloud-resolving prototype

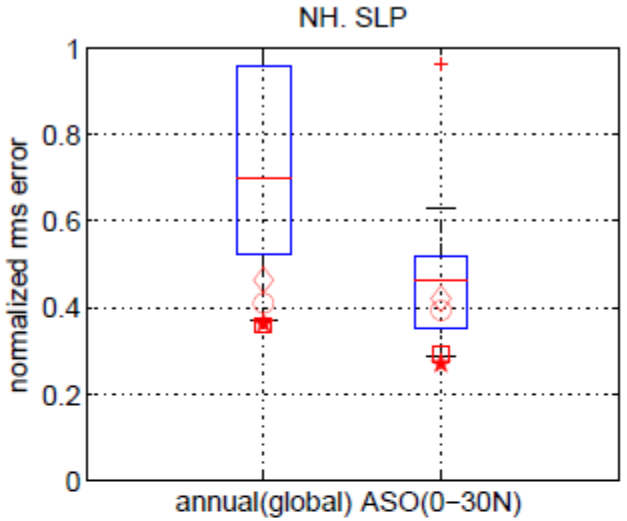


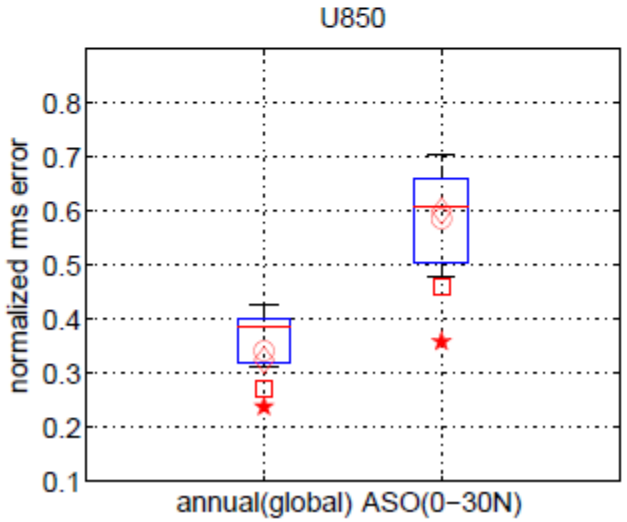
Cold bias disappears as resolution increases

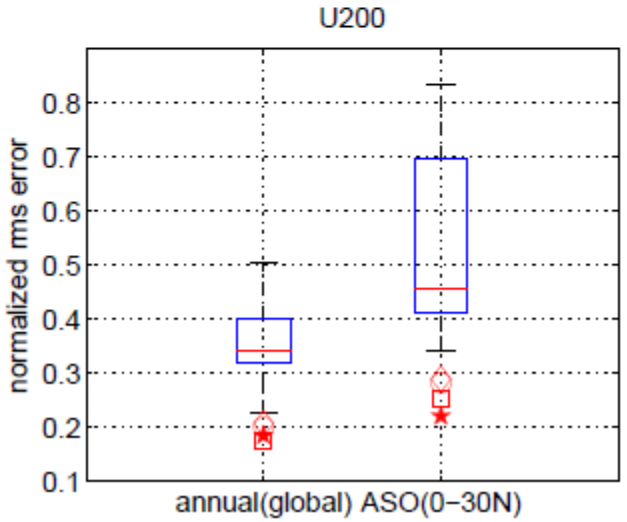
Climate Model inter-comparisons:

GFDL finite-volume models vs. 10 other IPCC models

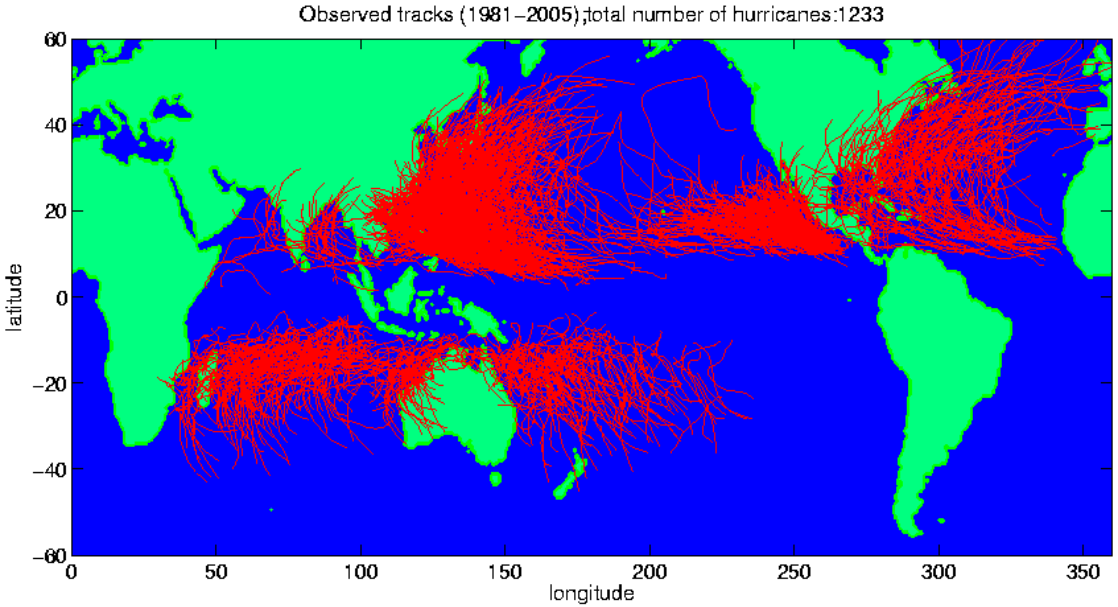




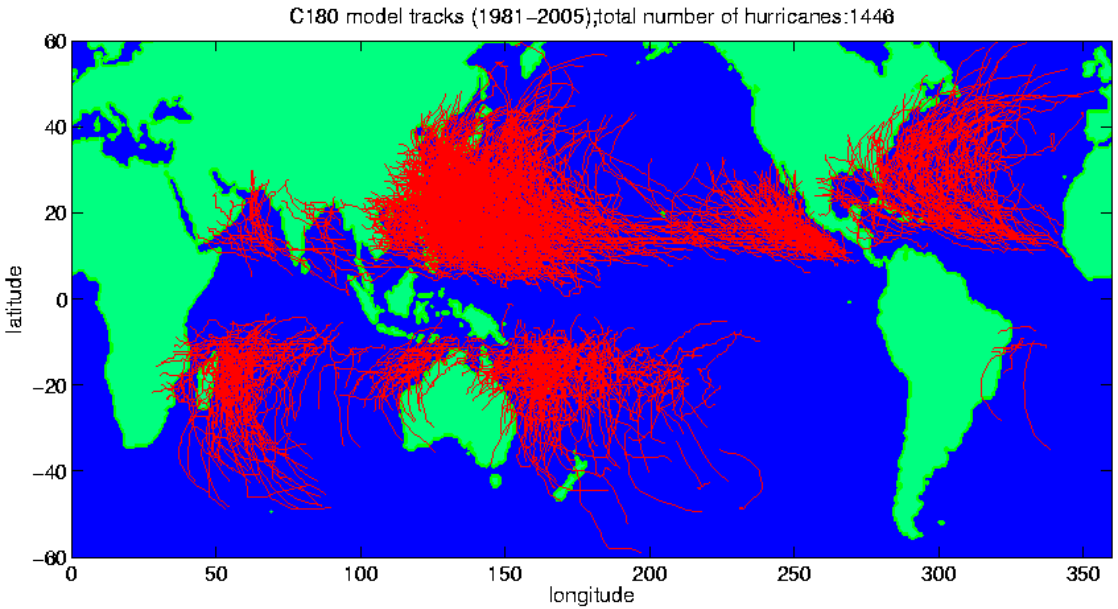




Observed cyclone tracks: 1981-2005



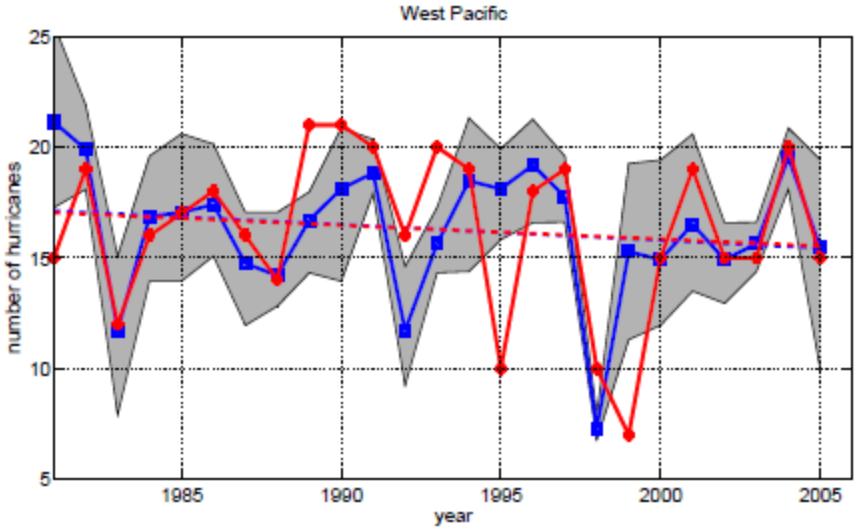
Simulated tracks: 1981-2005 (C180 model)



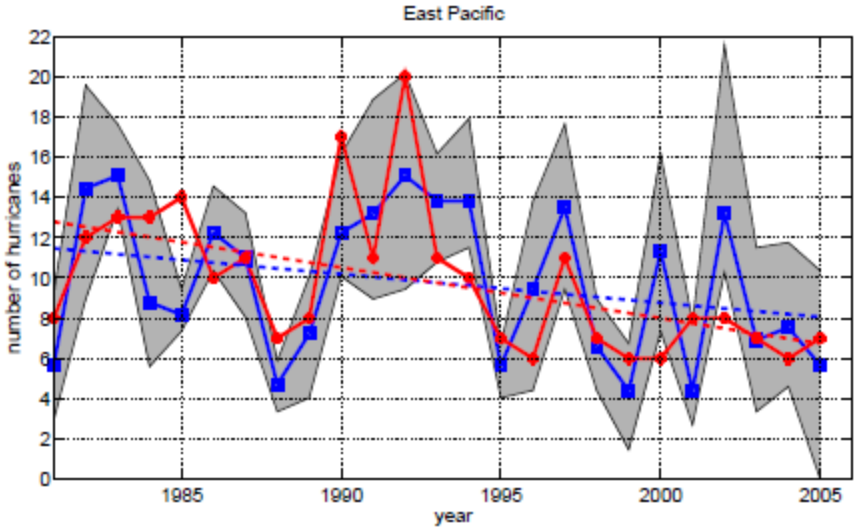
← One realization

Inter-annual cycle/trend (1981-2005)

Number of West Pacific Typhoons



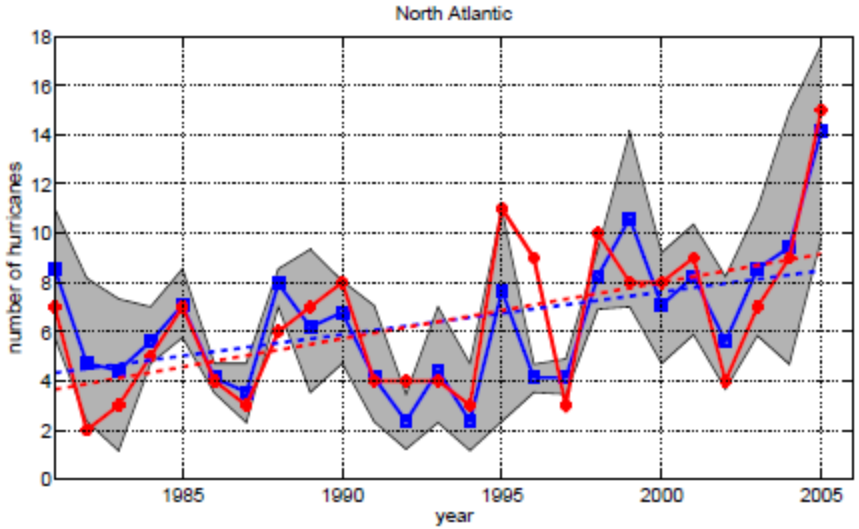
Number of East Pacific hurricanes



Reds: observed

Blue: model (4 realizations)

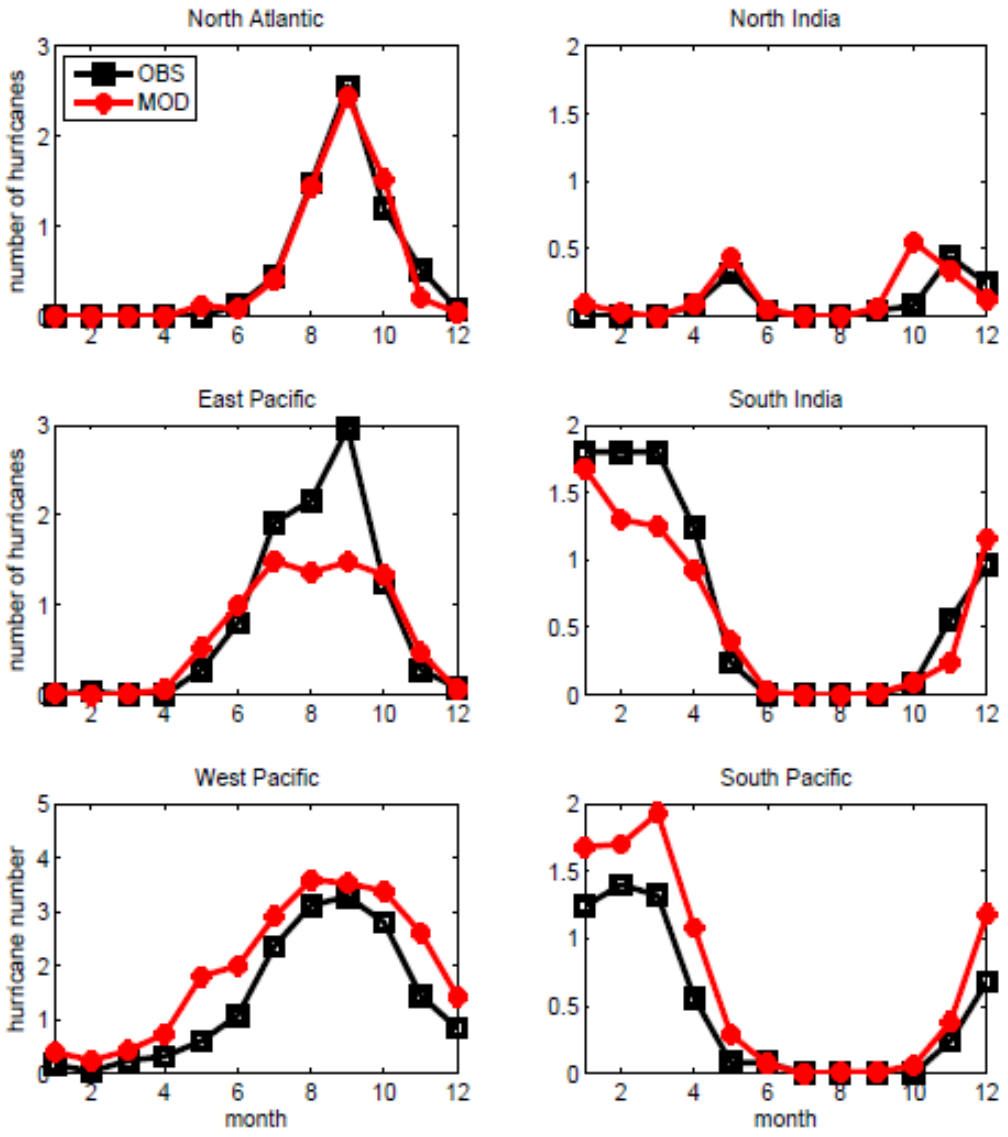
Number of North Atlantic hurricanes



Model-obs correlation ~ 0.83

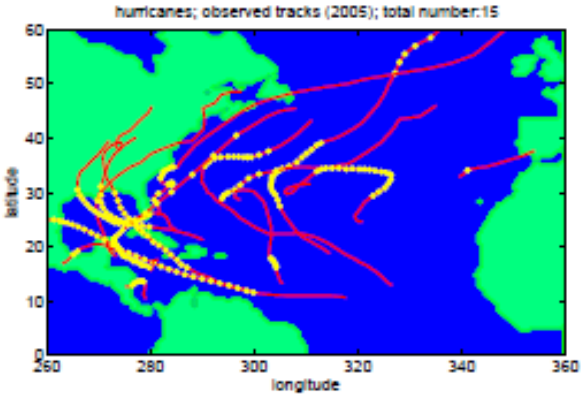
Seasonal cycle of hurricanes (1981-2005)

(red: 4-member ensemble)

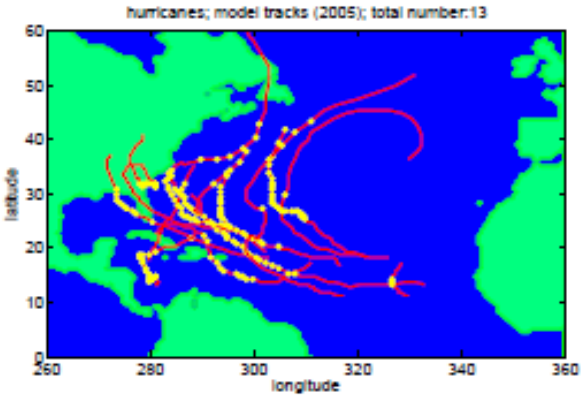


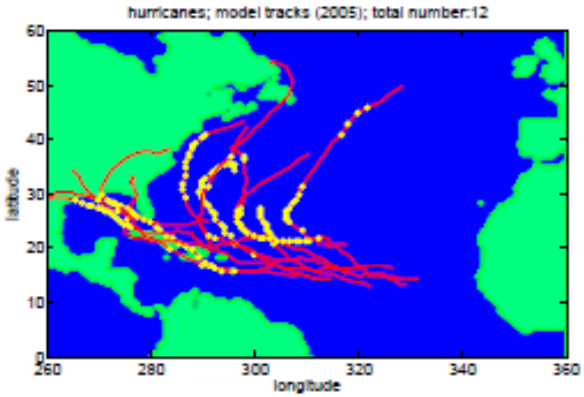
2005 Hurricane season

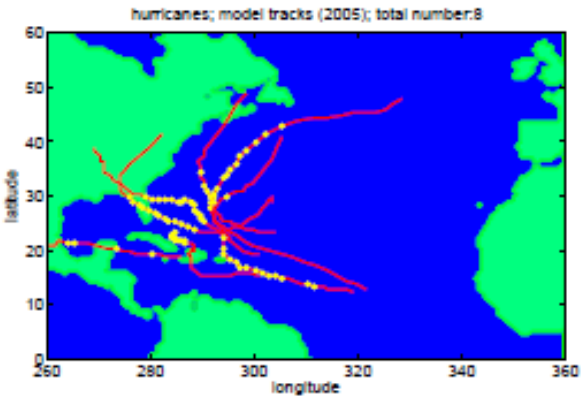
C180 climate model ensemble vs. observed

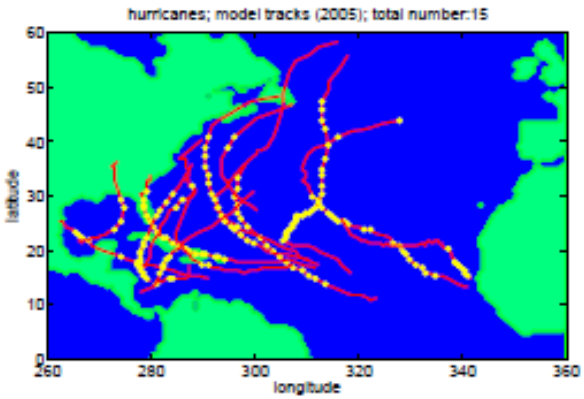


← Observed tacks

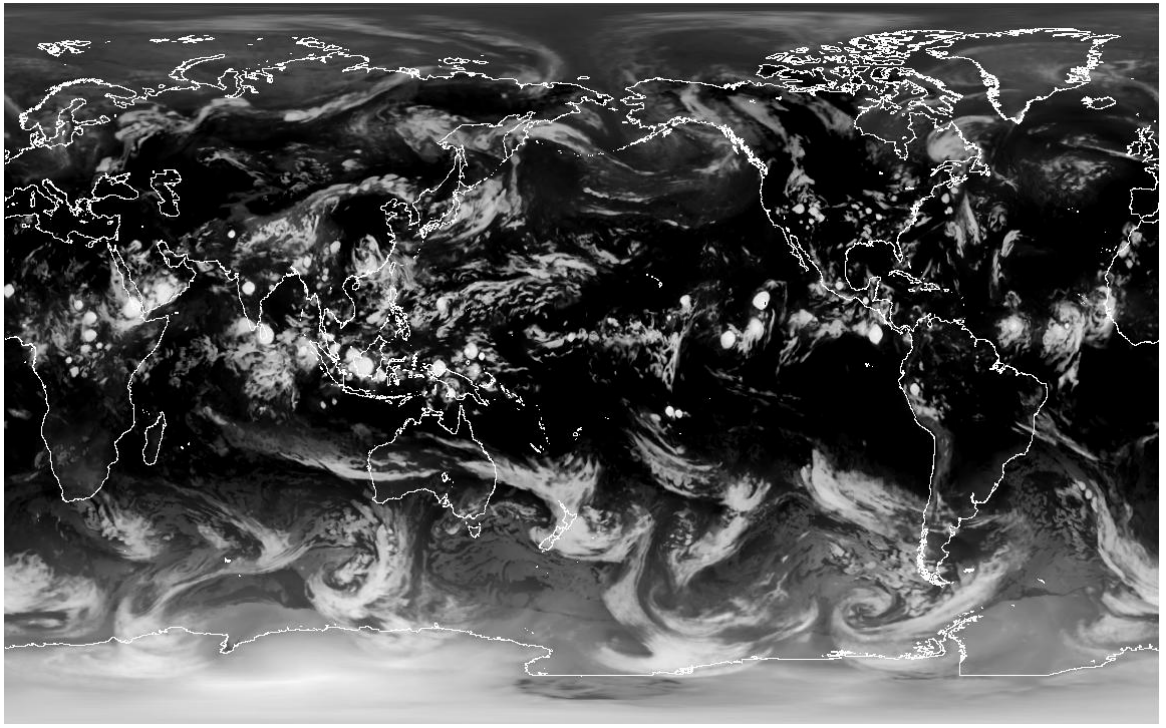






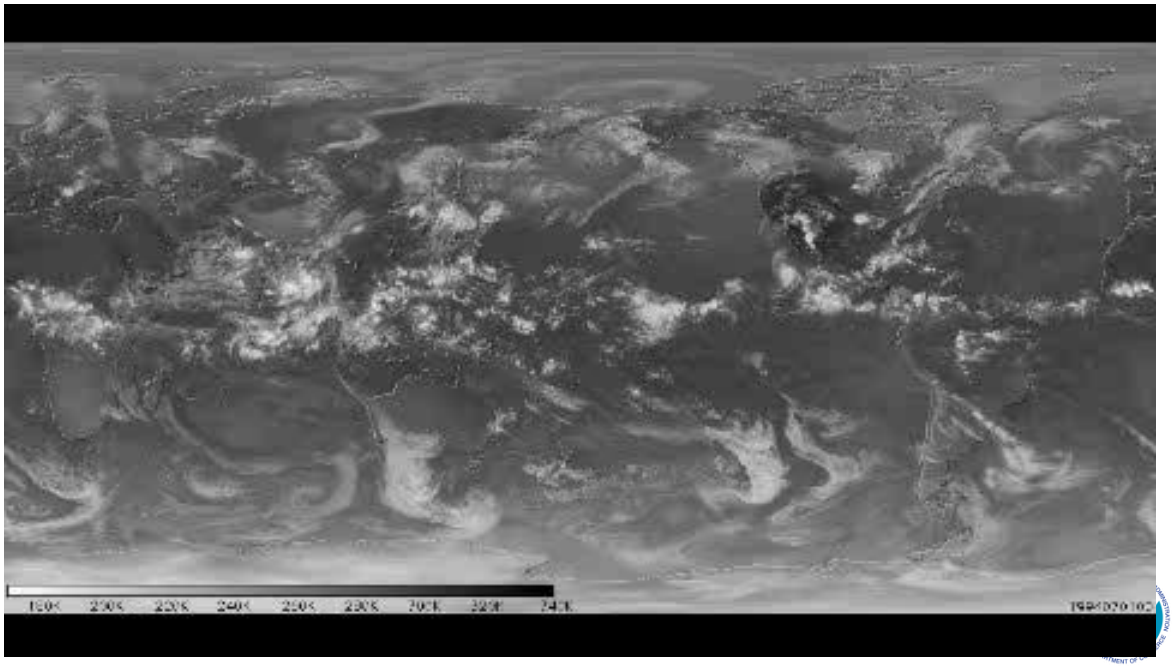


One-month animation of "clouds"



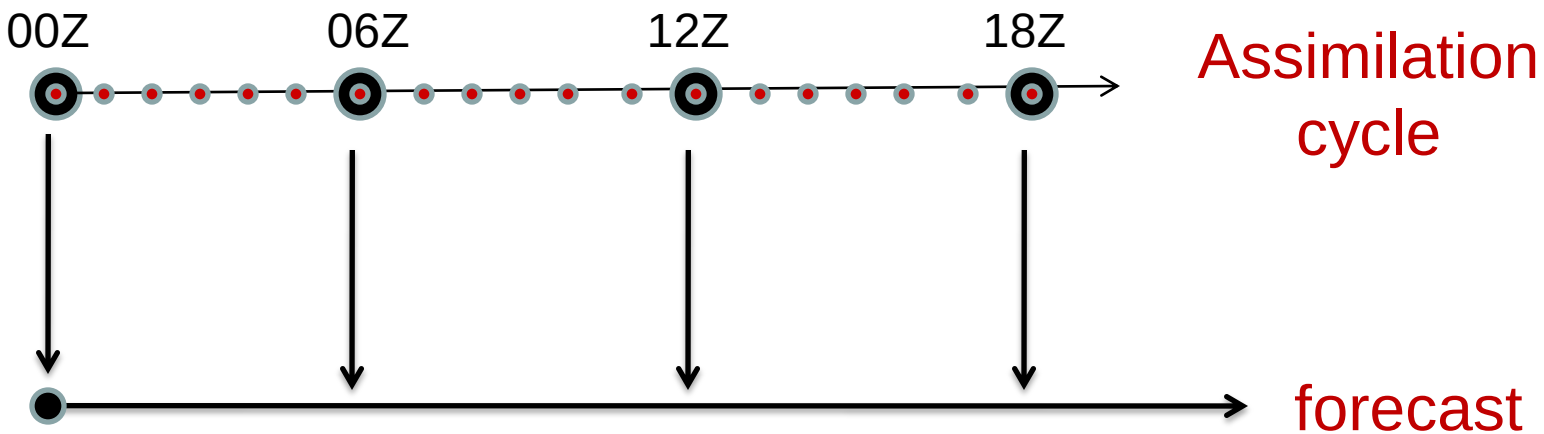
Which one is **model** OLR?

Which one is satellite **observation**?

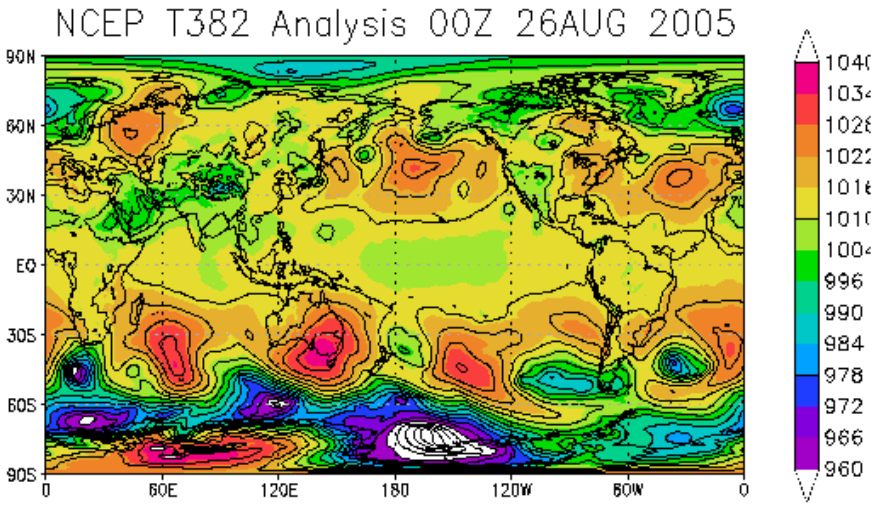


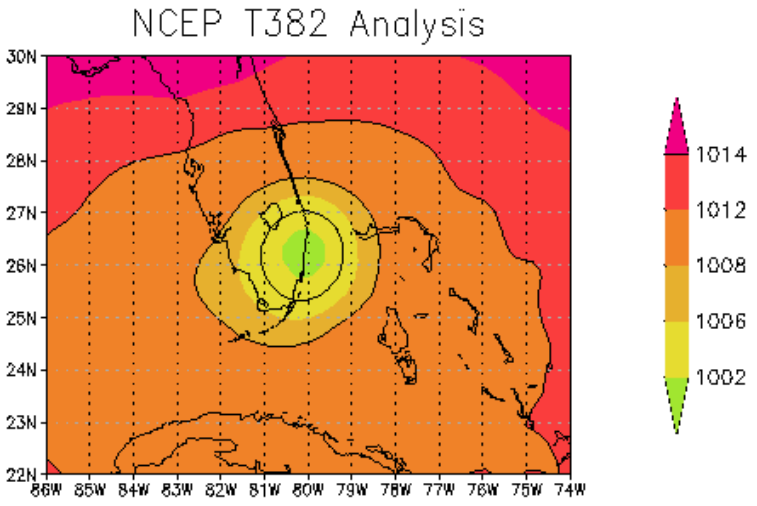
A simple 4D data assimilation for tropical cyclone prediction:

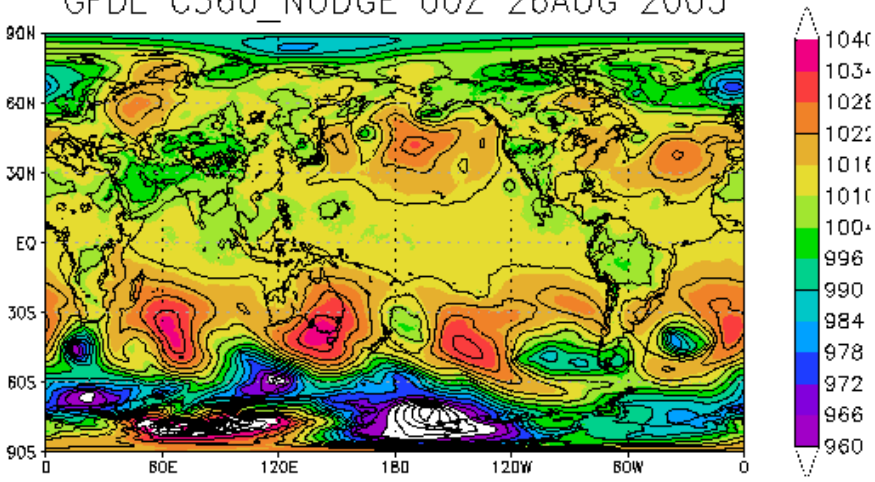
Large-scale nudging (using NCEP T382L64 gridded analysis) + storm-scale 4D (time continuous) vortex-breeding

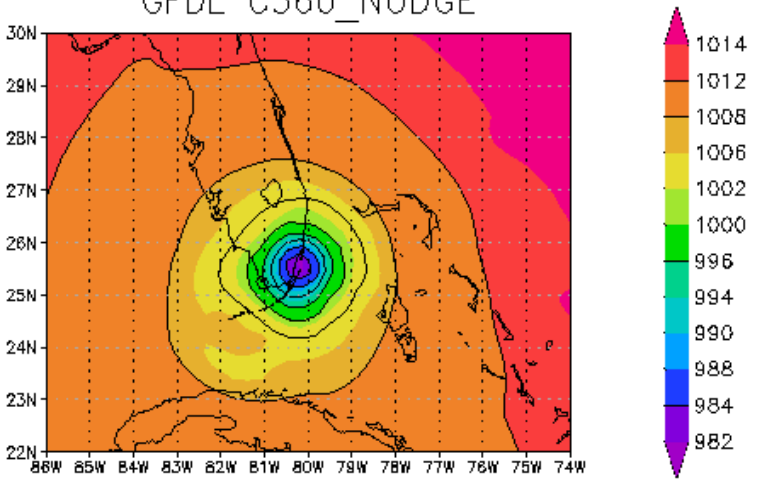


SLP: Katrina 1st US landfall (~ 4 days before 2nd landfall)



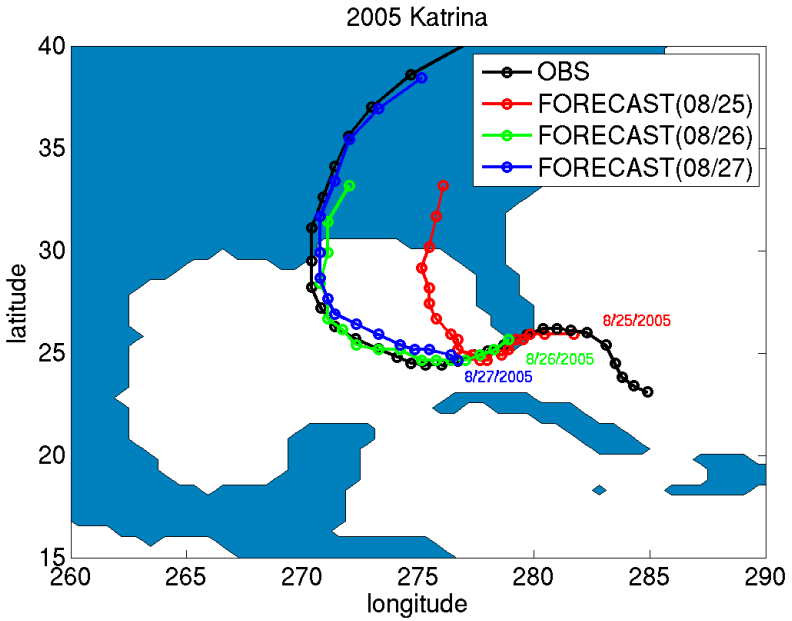






Katrina forecasts

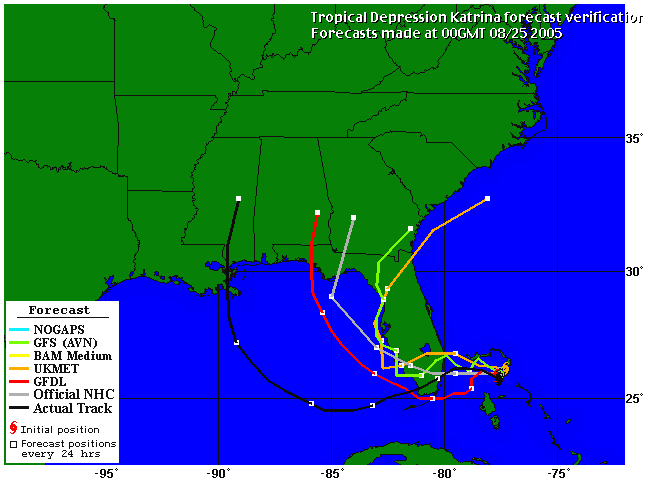
GFDL C360 HiRam



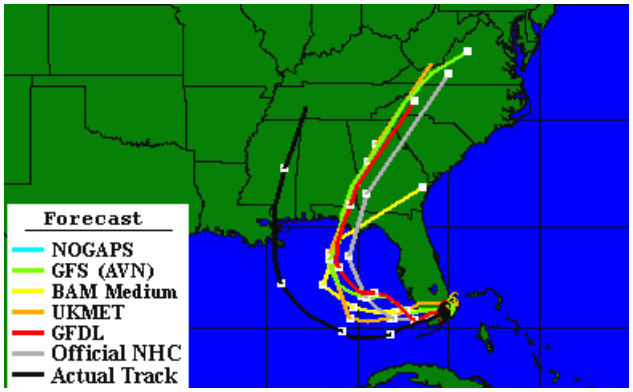
2005 operational models

www.weatherundergroud.com

00Z 08/25

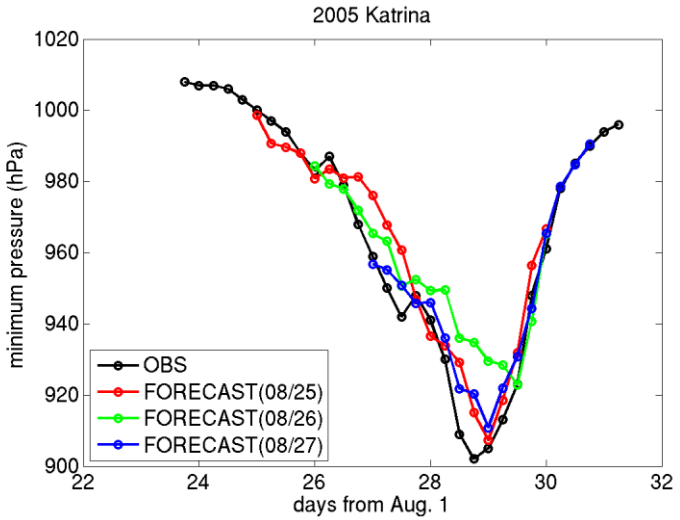


00Z 08/26

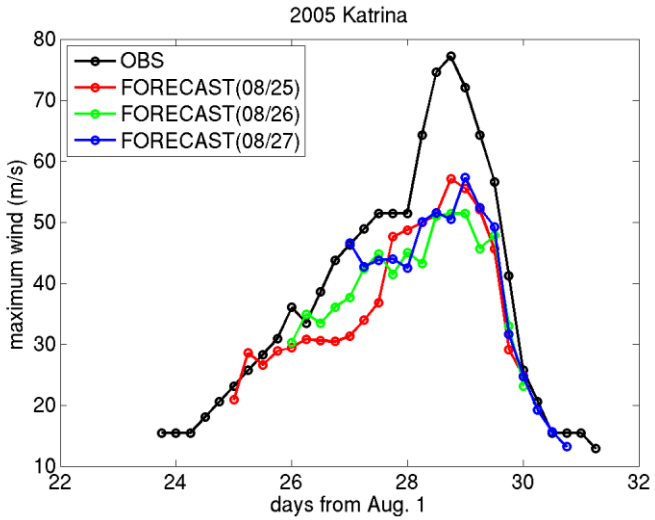


Intensity prediction of Katrina

Sea-level-pressure

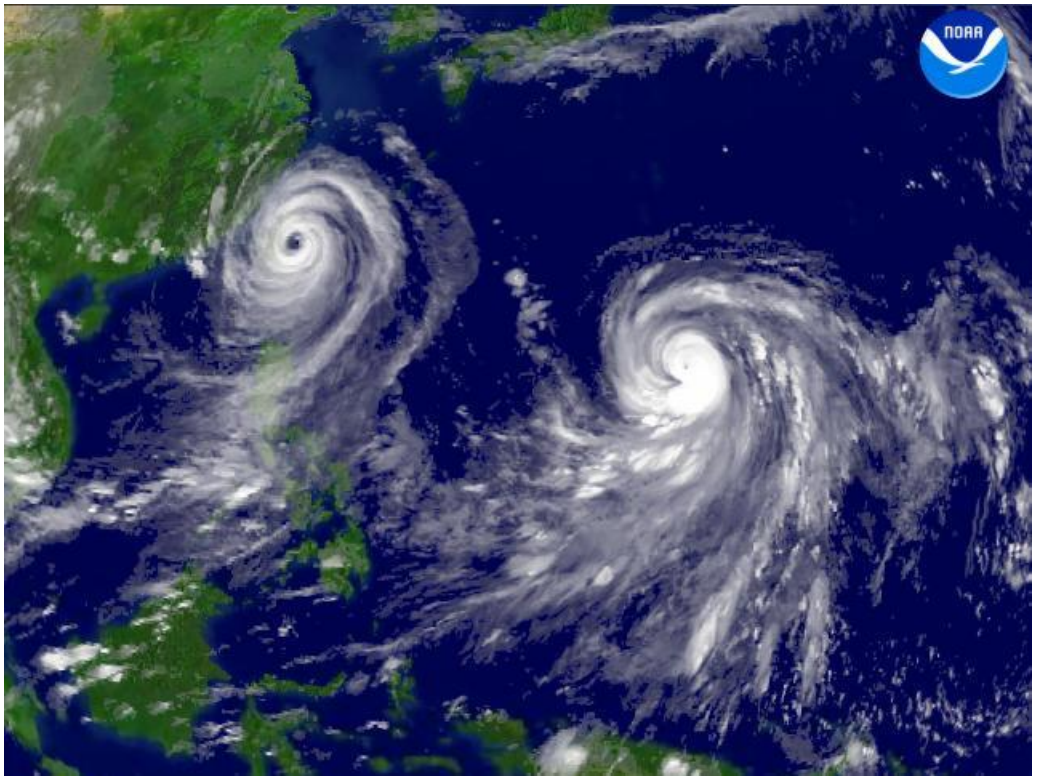


10-meter winds



Can tropical cyclone genesis be predictable?

Talim and Nabi at ~ 12Z 20050831

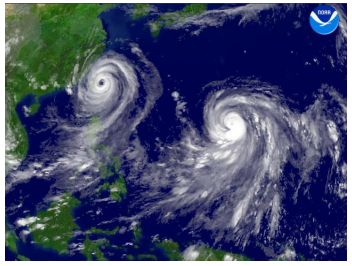


Birth dates:

Talim: 27 Aug 2005

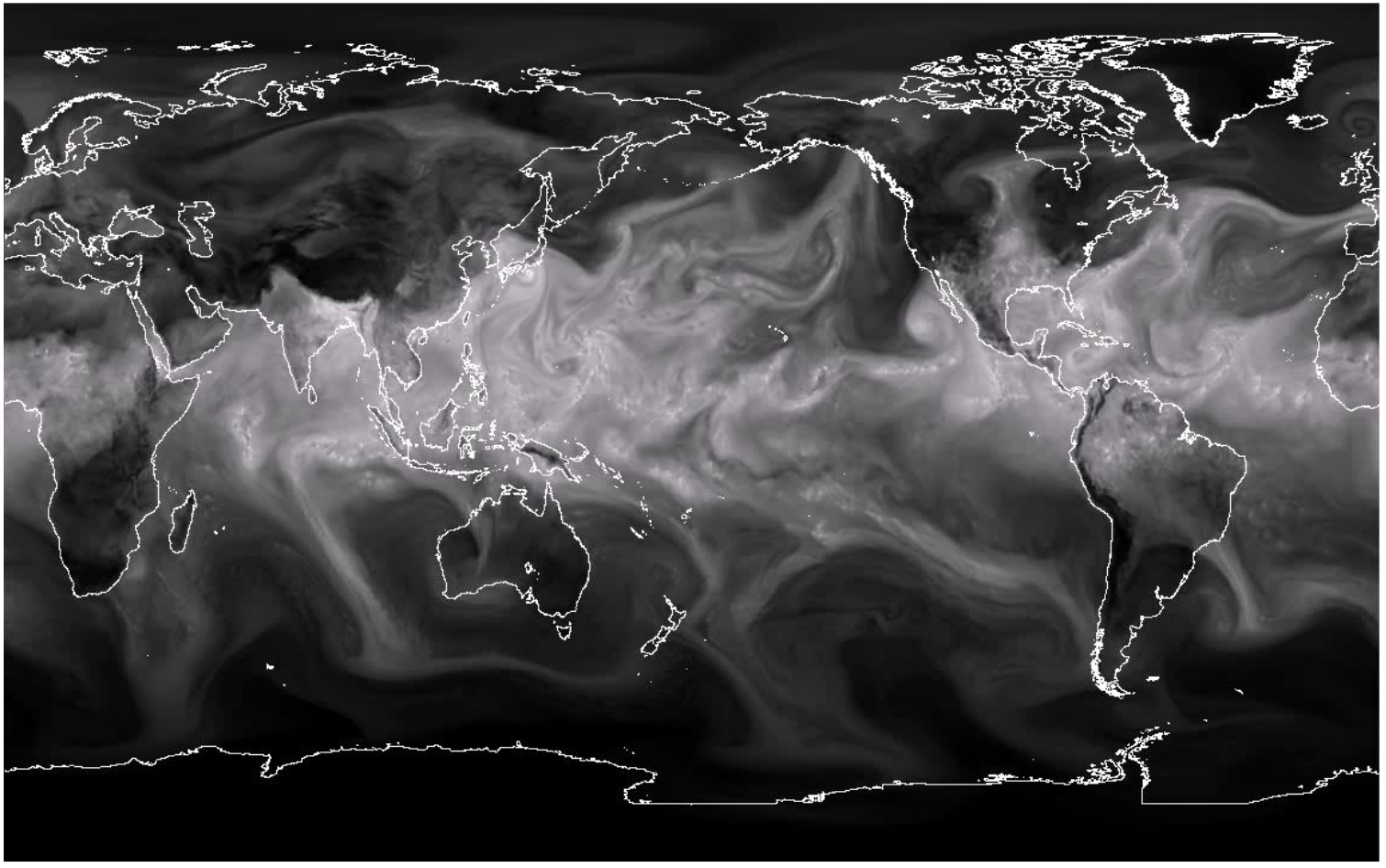
Nabi: 29 Aug 2005

Talim and Nabi
12Z 20050831



Katrina: 5-day forecast initialized on 00Z Aug 26, 2005

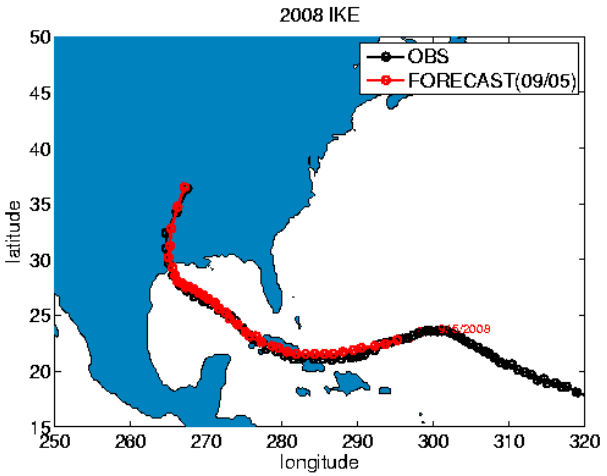
Column Water Vapor

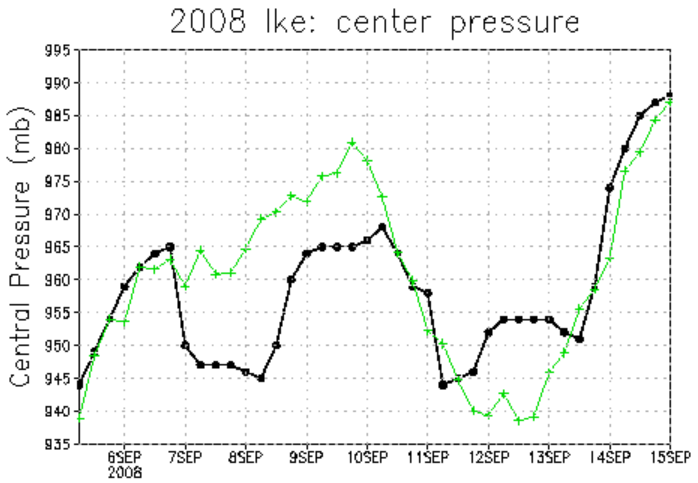


Global cloud-resolving prototype model
Resolution: C720 (~13-km)
5-day forecast of Wilma (00Z 18 Oct 2005)

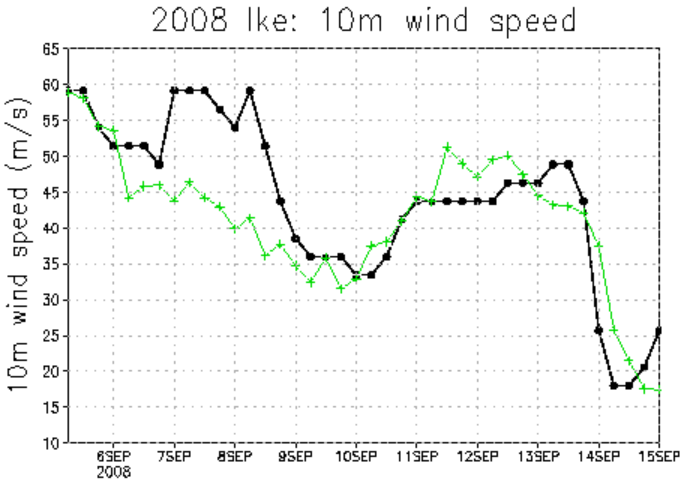
Can 10-day hurricane forecast be skillful?

Hurricane Ike (2008)
10-day forecast: 00Z 20080906-20080915





Water vapor



Ongoing works & Future plans:

- C360 (~25 km) resolution for IPCC AR5 “time slice” experiments and for seasonal hurricane/typhoon predictions
- Coupled ocean + “Wave Watch III” model (to improve surface momentum & heat fluxes)
- Global “*cloud-resolving*” (minimal convective parameterization) multi-year simulations at the C2000 (4~5km) resolution to be carried at US Dept. of Energy’s Argonne National Laboratory. Platform: IBM Blue Gene (P/Q) scaling from 200K and up to one million cores.
- Make the model components (in particular, dynamics & cloud microphysics) suitable for global 1-km simulation – in case they build the machine